Chapter 12: Stoichiometry

Section 12.1 The Arithmetic of Equations (pg.353-358)

1. Interpret balanced chemical equations in terms of atoms, molecules, moles, mass and volume.
2. Demonstrate the Law of Conservation of Mass in a balanced chemical equation.

Section 12.2 Chemical Calculations (pg. 359-366)

1. Determine mole rations between reactants and products in a chemical reaction.
2. Perform Mass-Mass stoichiometry between two substances in a chemical reaction.
3. Perform Mass-Particle, Mass-Volume (at STP), Particle-Volume (at STP), Particle-Particle and Volume-Volume (at STP) stoichiometry between two substances in a chemical reaction.

Section 12.3 Limiting Reagent and Percent Yield (pg. 368-375)

1. Identify the limiting reagent and excess reagent in a chemical reaction.
2. Determine the theoretical yield of a chemical reaction.
3. Calculate the percent yield of a chemical reaction given an experimental yield.

Written Work

Chapter 12: p. 379-382 # 36-38 (for 36a only) 40, 42, 45, 47, 48, 50, 51, 52, 55, 56, 59, 60, 61, 62, 63, 66, 77, 79, 80, 81, 82, 83.

p. 383 1-5

Supplemental Questions

Real-Life Stoichiometry

1. If you’re a camel……

It is a fallacy that camels store water in their humps. Their humps are actually a repository of a fat called tristearin (C57H110O6). When tristearin is metabolized through complete combustion, not only is energy produced but so is water.

* 1. Write the balanced equation for the complete combustion of tristearin.
  2. The average dromedary weighs about 450kg and tristearin comprises about 15% of its total body mass. If all of the tristearin in the average dromedary was to undergo complete combustion. What mass of water would be produced?
  3. The combustion of tristearin actually results in the loss of water from camel as most of this water evaporates during respiration. A camel can lose as much as 25% of its body weight from water loss and still survive. An average size camel also has the ability to drink about 200L of water in 3 minutes. If a 450kg camel were to lose 25% of its mass due to water loss, how long would it take it to regain that loss through drinking water. *Remember: density of water is 1.0 g/ml*

1. If you are an automobile designer……

Air bags use a chemical reaction to inflate airbags in the event of a collision. Read this following short Scientific American article for information about how air bags work <http://www.scientificamerican.com/article.cfm?id=how-do-air-bags-work>

* 1. Write the balanced decomposition reaction for sodium azide.
  2. If it takes about 67.0L of nitrogen gas to fill an airbag perform the calculations to determine how much sodium azide is needed to create this volume of nitrogen gas. *Remember, this reaction does not occur under STP conditions so you must use the density of N2 which is 0.916 g/L.*
  3. One of the products of the reaction in (a) could be harmful to human beings. As a result, iron (III) oxide is added to an airbag to “neutralize” this chemical.

1. Write the balanced chemical equation for this reaction.
2. What type of chemical reaction is this?
3. If 67L of nitrogen gas were produced upon impact, would 50g of iron (III) oxide be sufficient to convert all of the sodium to sodium oxide. *Hint: first determine what mass of sodium would be produced in reaction (2a) and then determine the limiting reactant in (2ci).*
4. If you are a pharmaceutical scientist……

The production of pharmaceutical often involves multi-step complex chemical reactions that are not one hundred percent efficient. A great deal of research in the pharmaceutical industry is geared toward enhancing the efficiency drug production in order to eliminate waste and decrease the cost of medications.

Consider this hypothetical series of reactions.

2A + B 2C (80% efficient)

C + 2D E + 2F (66% efficient)

2F 4G + H (75% efficient)

The theoretical yield of compound G following this series of reactions would be 4 moles if each reaction were 100% efficient.

1. Assuming 100% efficiency, what would be your percent yield if you started with 5.2 moles of A and produced 8.9 moles of G?

1. If you were to start with 2 moles of A, how many moles of G would be your theoretical yield given the efficiencies listed for each reaction?
2. If you needed to produce 4 moles of G with these inefficiencies, how many moles of A would you need to start with?

**Mixed Stoichiometry Practice** Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Write and/or balance the following equations (remember the diatomic elements and to criss-cross charges for ionic compounds!!!) Use the mole ratios from the balanced equations to solve the following stoichiometry problems. Use units and labels in all conversions, and round your answer to sig figs.

|  |
| --- |
| 1. Potassium chlorate decomposes into potassium chloride and oxygen gas.   **Balanced Equation:**  How many moles of oxygen are produced when 3.0 moles of potassium chlorate decompose completely? |
| 1. Butane (C4H10) undergoes combustion.   **Balanced Equation:** \_\_\_\_\_ C4H10(l) + \_\_\_\_\_ O2(g) → \_\_\_\_\_ CO2(g) + \_\_\_\_\_ H2O(l)  How many grams of CO2 are produced when 88 g of O2 are reacted with an excess of butane? |
| 1. Water decomposes into hydrogen gas and oxygen gas by electrolysis.   **Balanced Equation:**   1. How many grams of hydrogen will be produced when 6.0 moles of oxygen are produced? 2. How many grams of water are required to produce 1.5L of hydrogen at STP? |

|  |
| --- |
| 1. Cobalt(II) chloride reacts with fluorine in a single replacement reaction to produce cobalt(II) fluoride and chlorine gas.   **Balanced Equation:** \_\_\_\_\_ CoCl2 + \_\_\_\_\_ F2 🡪 \_\_\_\_\_ CoF2 + \_\_\_\_\_ Cl2  How many liters of fluorine are required to produce 290.8 g of cobalt(II) fluoride? *Density of Fluorine is 1.7 g/L under the conditions of this experiment.* |
| 1. Balance the following equation.   \_\_\_\_ SrCl2(aq) + \_\_\_\_\_ H2SO4(aq) → \_\_\_\_\_HCl(aq) + \_\_\_\_SrSO4(s)  What is the mass of strontium chloride that reacts with 300.0 g of sulfuric acid? |
| 1. Solid iron(III) oxide reacts with hydrogen gas to form iron and water.   **Balanced Equation:**   1. How many grams of iron are produced when 450 grams of iron(III) oxide are reacted? 2. How many grams of water will be produced when 3.2L of hydrogen gas react completely with iron(III) oxide at STP? |

**LIMITING REAGENT Practice Problems**

1. At high temperatures, sulfur combines with iron to form the brown-black iron (II) sulfide:

Fe (s) + S (l) 🡪 FeS (s)

In one experiment, 7.62 g of Fe are allowed to react with 8.67 g of S.

1. What is the limiting reagent, and what is the reactant in excess?
2. Calculate the mass of FeS formed.
3. Arcylonitrile, C3H3N, is the starting material for the production of a kind of synthetic fiber acrylics) and can be made from propylene, C3H6, by reaction with nitric oxide, NO, as follows:

4 C3H6 (g) + 6 NO (g) → 4 C3H3N (s) + 6 H2O (l) + N2 (g)

What mass of C3H3N can be made when 21.6 g of C3H6 react with 21.6 g of nitric oxide?

1. Formic acid, HCHO2, burns in oxygen to form carbon dioxide and water as follows:

HCHO2 (aq) + O2 (g) → 2 CO2 (g) + 2 H2O (l).

If a 3.15-g sample of formic acid was burned in 2.0 L of oxygen, what volume of carbon dioxide would be produced? (Assume the reaction occurs at standard temperature and pressure, STP.)

1. Zinc metal reacts with hydrochloric acid to produce zinc chloride and hydrogen gas.
2. Balance the following reaction: \_\_\_ Zn (s) +\_\_\_ HCl (aq) → \_\_\_ZnCl2 (aq) + \_\_\_H2 (g)
3. A 3.50-g sample of zinc metal is allowed to react with 2.50 g of hydrochloric acid.

Complete the following table:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Reactants/products | Zn (grams) | HCl (grams) | ZnCl2 (grams) | H2 (L) |
| Before reaction |  |  |  |  |
| After reaction | 1.26 g |  |  |  |

1. Consider the reaction: MnO2 + 4 HCl → MnCl2 + Cl2 + 2 H2O

If 0.45 mols of MnO2 can react with 48.2 g of HCl, how many grams of Cl2 could be produced?

1. One of the components of the fuel mixture on the Apollo lunar module involved a reaction with hydrazine, N2H4, and dinitrogen tetraoxide, N2O4. If the balanced equation for this reaction is

2 N2H4 (l) + N2O4 (g) → 3 N2 (g) + 4 H2O (g),

What volume of N2 gas (measured at STP) would result from the reaction of 1500 kg of hydrazine and 1000 kg of N2O4?

1. Chlorine gas reacts with silica, SiO2, and carbon to give silicon tetrachloride and carbon monoxide.
   1. Balance the following equation: \_\_Cl2 (g) + \_\_SiO2 (s) + \_\_C (s) → \_\_SiCl4 (l) + \_\_CO (g)
   2. How much CO gas can be produced from 15.0 g of silica?

Theoretical and Percent Yield Worksheet

1. Given the following equation:

\_\_\_\_\_ K2PtCl4  + \_\_\_\_\_ NH3   --------> \_\_\_\_\_ Pt(NH3)2Cl2  + \_\_\_\_\_ KCl

1. Balance the equation.
2. Determine the theoretical yield of KCl if you start with 34.5 grams of NH3.
3. Starting with 34.5 g of NH3, and you isolate 76.4 g of Pt(NH3)2Cl2, what is the percent yield?
4. Given the following equation:

  H3PO4    +     3 KOH    ------>  K3PO4     +  3 H2O

1. If 49.0 g of H3PO4 is reacted with excess KOH, determine the percent yield of K3PO4 if you isolate 49.0 g of K3PO4.
2. Given the following equation:

  Al2(SO3)3    +  6 NaOH  ------> 3 Na2SO3    +   2 Al(OH)3

1. If you start with 389.4 g of Al2(SO3)3 and you isolate 212.4 g of Na2SO3, what is your percent yield for this reaction?
2. Given the following equation:

 Al(OH)3 (s)   +  3 HCl (aq)  ------->   AlCl3 (aq)   +   3 H2O (l)

1. If you start with 50.3 g of Al(OH)3 and you isolate 39.5 g of AlCl3, what is the percent yield?
2. Given the following equation:

 K2CO3    +     HCl   -------->        H2O     +    CO2    +    KCl

1. Balance the equation.
2. Determine the theoretical yield of KCl if you start with 34.5 g of  K2CO3.
3. Starting with 34.5 g of K2CO3, and you isolate 3.4 g of H2O, what is the percent yield?
4. Given the following equation:

  H2SO4    +      Ba(OH)2    ------>  BaSO4     +   H2O

1. If 98.0 g of H2SO4 is reacted with excess Ba(OH)2, determine the percent yield of BaSO4 if you isolate 213.7 g of BaSO4.
2. Given the following equation:

CaCl2   +   Li3PO4  ------>  LiCl    +   Ca3(PO4)2

1. If you start with 82.4 g of CaCl2 and you isolate 82.4 g of Ca3(PO4)2, what is your percent yield for this reaction?

8. Given the following equation:

 Cr(OH)3    +   HI   ------->   CrI3    +   H2O

a) If you start with 50.3 g of Cr(OH)3 and you isolate 39.5 g of CrI3, what is the percent yield?

Moles and stoichiometry practice problems (from Chapter 3 in Brady, Russell, and Holum’s *Chemistry, Matter and its Changes, 3rd Ed.*)

**Concept of mole/molar ratio**

1) How many moles of sodium atoms correspond to 1.56x1021 atoms of sodium?

2) How many moles of Al atoms are needed to combine with 1.58 mol of O atoms to make aluminum oxide, Al2O3?

3) How many moles of Al are in 2.16 mol of Al2O3?

4) Aluminum sulfate, Al2(SO4)3, is a compound used in sewage treatment plants.

a. Construct a pair of conversion factors that relate moles of aluminum to moles of sulfur for this compound

b. Construct a pair of conversion factors that relate moles of sulfur to moles of Al2(SO4)3

c. How many moles of Al are in a sample of this compound if the sample also contains 0.900 mol S?

d. How many moles of S are in 1.16 mol Al2(SO4)3?

5) How many moles of H2 and N2 can be formed by the decomposition of 0.145 mol of ammonia, NH3?

6) What is the total number of atoms in 0.260 mol of glucose, C6H12O6?

7) What is the mass of 1.00 mol of each of the following elements?

a. Sodium

b. Sulfur

c. Chlorine

8) Determine the mass in grams of each of the following:

a. 1.35 mol Fe

b. 24.5 mol O

c. 0.876 mol Ca

d. 1.25 mol Ca3(PO4)2

e. 0.625 mol Fe(NO3)3

f. 0.600 mol C4H10

g. 1.45 mol (NH4)2CO3

9) Calculate the number of moles of each compound:

a. 21.5 g CaCO3

b. 1.56 g NH3

c. 16.8 g Sr(NO3)2

d. 6.98 μg Na2CrO4

**Percent composition and empirical formulas**

10) Calculate the percentage composition by mass of each element in the following compounds:

a. NaH2PO4

b. NH4H2PO4

c. (CH3)2CO

11) Phencyclidine is C17H25N. A sample suspected of being this illicit drug was found to have a percentage composition of 83.71% C, 10.42% H, and 5.61% N. Do these data acceptably match the theoretical data for phencyclidine?

12) How many grams of O are combined with 7.14x1021 atoms of N in the compound N2O5?

13) Quantitative analysis of a sample of sodium pertechnetate with a mass of 0.896g found 0.111g Na and 0.477g technetium (Tc). The remainder was oxygen. Calculate the empirical formula of sodium pertechnetate, NaxTcyOz.

14) A substance was found to be composed of 22.9% Na, 21.5% B, and 55.7% O. What is the empirical formula of this compound?

15) When 0.684 g of an organic compound containing only C, H, and O was burned in oxygen 1.312g CO2 and 0.805g H2O were obtained. What is the empirical formula of the compound?

**Balancing equations**

16) Write the equation that expresses in acceptable chemical shorthand the following statement: “Iron can be made to react with molecular oxygen (O2) to give iron oxide with the formula Fe2O3”

17) Balance the following reactions:

a. Ca(OH)2 + HCl 🡪 CaCl2 + H2O

b. AgNO3 + CaCl2 🡪 Ca(NO3)2 +AgCl

c. Fe2O3 + C 🡪 Fe + CO3

d. NaHCO3 + H2SO4 🡪 Na2SO4 + H2O + CO2

e. C4H10 + O2 🡪 CO2 +H2O

f. Mg(OH)2 + HBr 🡪 MgBr2 + H2O

g. Al2O3 + H2SO4 🡪 Al2(SO4)3 + H2O

h. KHCO3 + H3PO4 🡪 K2HPO4 + H2O + CO2

i. C9H10O + O2 🡪 CO2 + H2O

**Stoichiometry/limiting reactants**

18) Chlorine is used by textile manufacturers to bleach cloth. Excess chlorine is destroyed by its reaction with sodium thiosulfate, Na2S2O3:

Na2S2O3(aq) + 4Cl2(g) + 5H2O(aq) 🡪 2NaHSO4(aq) + 8HCl(aq)

a. How many moles of Na2S2O3 are needed to react with 0.12mol of Cl2?

b. How many moles of HCl can form from 0.12mol of Cl2?

c. How many moles of H2O are required for the reaction of 0.12mol of Cl2?

d. How many moles of H2O react if 0.24mol HCl is formed?

19) The incandescent white of a fireworks display is caused by the reaction of phosphorous with O2 to give P4O10.

a. Write the balanced chemical equation for the reaction.

b. How many grams of O2 are needed to combine with 6.85g of P?

c. How many grams of P4O10 can be made from 8.00g of O2?

d. How many grams of P are needed to make 7.46g P4O10?

20) In *dilute* nitric acid, HNO3, copper metal dissolves according to the following equation:

3Cu(s) + 8HNO3(aq) 🡪 3Cu(NO3)2(aq) + 2NO(g) + 4H2O(aq)

How many grams of HNO3 are needed to dissolve 11.45g of Cu?

21) The reaction of powdered aluminum and iron(II)oxide,

2Al(s) + Fe2O3(s) 🡪 Al2O3(s) + 2Fe(l)

produces so much heat the iron that forms is molten. Because of this, railroads use the reaction to provide molten steel to weld steel rails together when laying track. Suppose that in one batch of reactants 4.20mol Al was mixed with 1.75mol Fe2O3.

a. Which reactant, if either, was the limiting reactant?

b. Calculate the mass of iron (in grams) that can be formed from this mixture of reactants.

22) Silver nitrate, AgNO3, reacts with iron(III) chloride, FeCl3, to give silver chloride, AgCl, and iron(III) nitrate, Fe(NO3)3. A solution containing 18.0g AgNO3 was mixed with a solution containing 32.4g FeCl3. How many grams of which reactant *remains* after the reaction is over?

**Theoretical and percent yield**

23) Barium sulfate, BaSO4, is made by the following reaction:

Ba(NO3)2(aq) + Na2SO4(aq) 🡪 BaSO4(s) + 2NaNO3(aq)

An experiment was begun with 75.00g of Ba(NO3)2 and an excess of Na2SO4. After collecting and drying the product, 63.45g BaSO4 was obtained. Calculate the theoretical yield and percent yield of BaSO4.

24) Aluminum sulfate can be made by the following reaction:

2AlCl3(aq) + 3H2SO4(aq) 🡪 Al2(SO4)3(aq) + 6HCl(aq)

It is quite soluble in water, so to isolate it the solution has to be evaporated to dryness. This drives off the volatile HCl, but the residual solid has to be treated to a little over 200°C to drive off all the water. In one experiment, 25.0g of AlCl3 was mixed with 30.0g H2SO4. Eventually, 28.46g of pure Al2(SO4)3 was isolated. Calculate the percent yield.

**Answers**

1) 2.59x10−3mol Na atoms

2) 1.05mol Al

3) 4.32mol Al

4) a. 2mol Al/3mol S b. 3mol S/1mol Al2(SO4)3 c. 0.600mol Al d. 3.48mol S

5) 0.0725mol N2 and 0.218mol H2

6) 3.76x1024 atoms

7) a. 23.0g Na b. 32.1g S c. 35.3g Cl

8) a. 75.4g Fe b. 392g O c. 35.1g Ca d. 388g Ca3(PO4)2

e. 151g Fe(NO3)2 f. 34.9g C4H10 g. 139g (NH4)2CO3

9) a. 0.215mol b. 0.0916mol c. 0.0794mol d. 4.31x10−8mol

10) a. 19.2% Na, 1.68% H, 25.8% P, 53.3% O

b. 12.2% N, 5.26% H, 26.9% P, 55.6%O

c. 62.0% C, 10.4% H, 27.6% O

11) Theoretical data (83.89% C, 10.35% H, 5.76% N) are consistent with experimental results.

12) 0.474g O

13) NaTcO4

14) Na2B4O7

15) C2H6O

16) 4Fe + 3O2 🡪 2Fe2O3

17)

a. Ca(OH)2 + 2HCl 🡪 CaCl2 + 2H2O

b. 2AgNO3 + CaCl2 🡪 Ca(NO3)2 + 2AgCl

c. 2Fe2O3 + 3C 🡪 4Fe + 3CO3

d. 2NaHCO3 + H2SO4 🡪 Na2SO4 + 2H2O + 2CO2

e. 2C4H10 + 13O2 🡪 8CO2 + 10H2O

f. Mg(OH)2 + 2HBr 🡪 MgBr2 + 2H2O

g. Al2O3 + 3H2SO4 🡪 Al2(SO4)3 + 3H2O

h. 2KHCO3 + H3PO4 🡪 K2HPO4 + 2H2O + 2CO2

i. C9H10O + 14O2 🡪 9CO2 + 10H2O

18) a. 0.030mol Na2S2O3 b. 0.24mol HCl c. 0.15mol H2O

d. 0.15mol H2O

19) a. 4P + 5O2 🡪 P4O10 b. 8.85g O2 c. 14.2g P4O10 d. 3.26g P

20) 30.31g HNO3

21) a. limiting reactant is Fe2O3 b. 195g Fe is formed

22) 26.7g of FeCl3 are left over

23) theoretical yield = 66.98g BaSO4, % yield = 94.73%

24) % yield = 88.74%